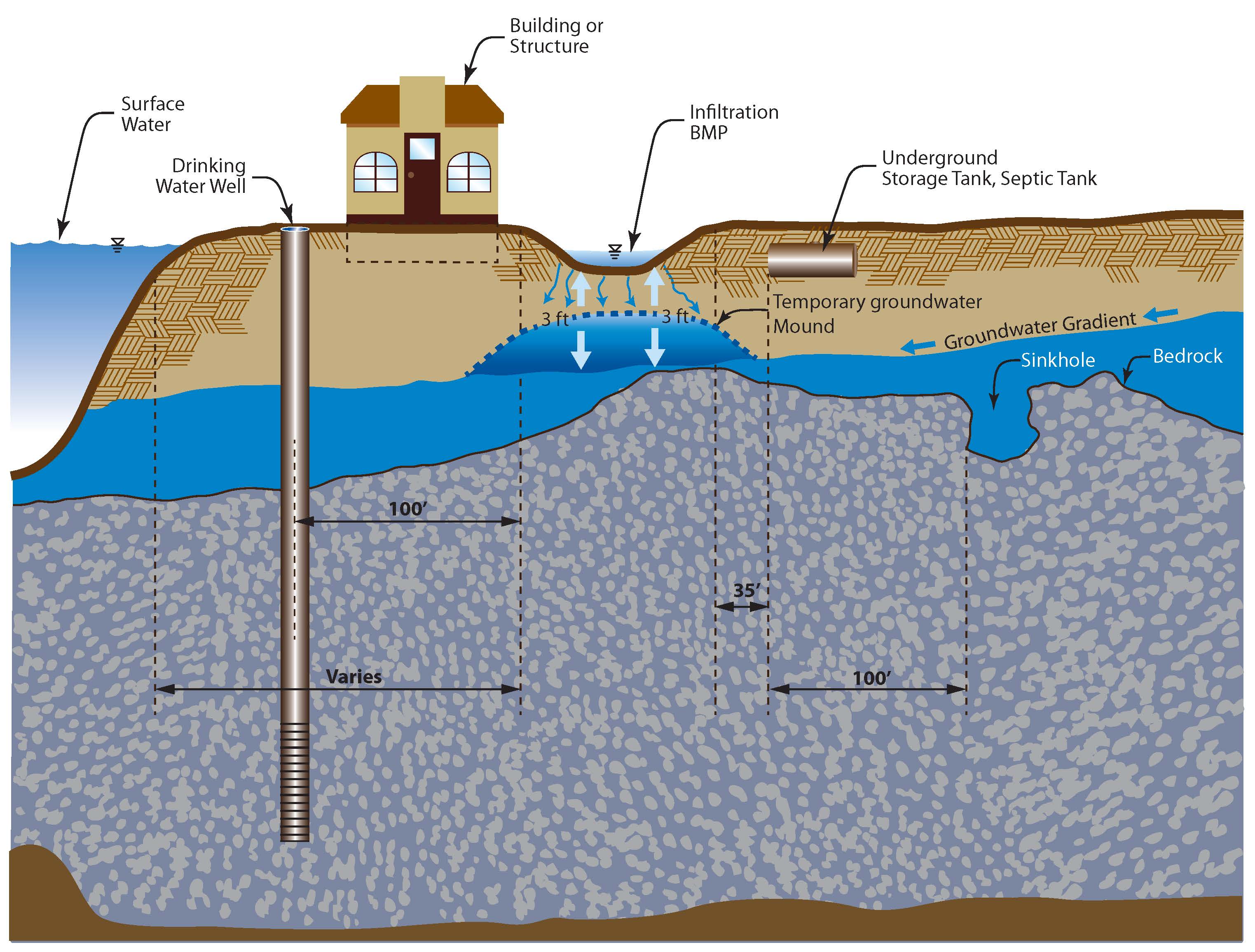
Section 2   
Constraints on Stormwater Infiltration

Several conditions can constrain the suitability, sizing, and/or location of an infiltration BMP at a particular site. Conditions may include geologic and hydrogeologic features, location to nearby drinking water sources, presence of contaminated soils/groundwater, and the likelihood of potential stormwater hotspots (PSHs), among others described in the following section. This discussion does not include constraints associated with limited space, local ordinance restrictions, or utilities.

2.1 Horizontal and Vertical Separation

Separation distance is defined as the distance from the closest point of a BMP to the particular feature being considered. Recommended and REQUIRED separation distances for infiltration BMPs are shown in **Figure 2.1** and discussed below. Specific information on separation distances can be found on each individual BMP page. Note that all REQUIRED statements in this section refer to requirements contained in the [NPDES/SDS Construction Stormwater (CSW) General Permit](http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.html) (CGP).



**Figure 2.1 Horizontal and vertical separation distances of infiltration BMPs** (Source: CDM Smith)

* + 1. Vertical Separation Distances

Vertical separation distance is the vertical distance from the bottom of a BMP to the top of the feature of concern. The shortest vertical distance is used in measuring the separation distance.

Seasonally Saturated Soils

Under the CGP, a three (3) foot vertical separation is REQUIRED between the bottom of any infiltration BMP and the top of seasonally saturated soils. Seasonally saturated soil is defined as the highest seasonal elevation in the soil that is evidenced by the presence of [redoximorphic features](ftp://ftp-fc.sc.egov.usda.gov/WLI/1212OldWLIfromUSGS/wli/Training/REDOX.PDF) or other parameters as assessed by a soils specialist. The temporary groundwater mound that develops below an operational infiltration BMP is not required to be a minimum of 3 feet below the bottom of the infiltration BMP. However, it is HIGHLY RECOMMENDED that this mound not penetrate into the infiltration BMP which could inhibit the pollutant removal within the media contained in the BMP. The base of the BMP may be raised to achieve the 3 foot separation. Additional detail on groundwater mounds can be found here.

Bedrock

Under the CGP a minimum 3 foot vertical separation is REQUIRED between the base of any constructed infiltration BMP and the top of the bedrock. The base of the BMP may be raised to achieve the 3 foot separation distance

Karst Bedrock

Karst topography is a geological formation shaped by the dissolution of a layer, or layers, of soluble bedrock. Groundwater in karst regions is particularly vulnerable to contamination. There is also concern about the formation of sinkholes resulting from focused infiltration. The CGP prohibits infiltration within areas that are 1,000 feet up gradient or 100 feet down gradient of an identified karst feature, unless approved by a local government with an approved Municipal Separate Storm Sewer System (MS4) NPDES permit. In addition, the 3 foot minimum separation to bedrock is applicable under the CGP. Additional detail on identifying and testing for Karst is detailed [here](#Karst).

2.1.2 Horizontal Separation Distances

Horizontal separation distance is the horizontal distance from the closest point of a BMP to the feature of concern. The shortest horizontal distance is used in determining the separation.

Drinking Water Wells

A 100 foot horizontal separation is REQUIRED between any infiltration BMP and drinking water well. This is to ensure there is adequate removal of pollutants before the infiltrating water reaches the drinking water well.

The CGP prohibits infiltration in areas within a Drinking Water Supply Management Area (DWSMA) as defined in [Minn. R. 4720.5100](https://www.revisor.mn.gov/rules/?id=4720.5100), subp. 13., unless approved by a local unit of government that has a current NPDES MS4 permit. Maps of [DWSMA areas](http://www.health.state.mn.us/divs/eh/water/swp/maps/) are available through the MN Department of Health.

Building or Other Structural Foundations

A horizontal separation of 10 feet is HIGHLY RECOMMENDED between any infiltration BMP and a structural foundation. Despite this recommended separation distance, the designer is encouraged to model the groundwater flow in the area using an unsaturated flow model to ensure that the infiltration BMP will not impact any surrounding structural foundations. Additional modeling is critical if the site contains a fill material which may result in a greater separation distance related to the greater void space often present in fill material which allows the infiltrating water to migrate laterally to the building foundation.

Surface Waters

Infiltration BMPs are not recommended if the infiltrating water contains a soluble pollutant that is likely to be transported via groundwater to a surface water impaired for that pollutant (e.g. chloride). There may also be local zoning or shoreline restrictions. Prior to the designing of any infiltration BMP that may impact surface waters, the user should consult the local city or county zoning office and watershed management organization, or the Soil and Water Conservation District.

Septic System Tank/Leach Field

A [35 foot](http://stormwater.pca.state.mn.us/index.php/BMP_design_considerations_for_ground_water_aquifer_protection) horizontal separation is recommended between any infiltration BMP and a septic tank or leach field.

Potential Contamination Sources

The CGP PROHIBITS infiltration when the infiltration system will be constructed in areas where high levels of contaminants in the soil or groundwater will be mobilized by the infiltrating water. At all other sites not regulated by the CGP, infiltration is not generally recommended in areas of contaminated soils for the same reason that the infiltrating water may mobilize the contamination. Stormwater infiltration may be feasible, however, on sites where the infiltration BMP can be isolated from the contaminants.

It is HIGHLY RECOMMENDED that stormwater infiltration BMPs not be installed in areas with contaminated groundwater down-gradient of the BMP, unless barriers or other devices that maintain a separation between the water infiltrating from the BMP and the contaminants are present. More information regarding stormwater management in contaminated areas can be found [here](#Contaminated).

Site Topography and Slopes

Unless slope stability analyses demonstrate otherwise, it is [HIGHLY RECOMMENDED](http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_Infiltration_basin) that infiltration practices be located a minimum horizontal distance of 200 feet up-gradient from the toe of a slope that is greater than 20 percent, and that the slopes in contributing drainage areas be limited to 15 percent. Guidance for managing infiltration and runoff to minimize the likelihood of slope erosion and slumping can be found at the [Toronto and Region Conservation website](http://www.trca.on.ca/dotAsset/83077.pdf) and The University of [Wisconsin Sea Grant Institute](http://www.seagrant.umn.edu/downloads/ch003.pdf) website.

2.1.3 Methods for Determining Separation Distances

Horizontal separation distances can be determined using simple measurement devices such as a GPS, survey, or even something as basic as a tape measure or measuring wheel. Distances should be measured from the edge of the BMP to the edge of the area of interest.

Vertical separation distances require subsurface investigations. Information on determining the vertical distance to bedrock or groundwater can be found [here](#Shallow_GW_Invest).

* 1. Shallow Groundwater

2.2.1 What is Shallow Groundwater?

Shallow groundwater is a condition where the seasonal high groundwater table, or saturated soil, is less than 3 feet from the land surface. There is a large portion of the state (more than 50 percent) where the seasonal high water table is located less than 3 feet from the surface. In these areas it may be impossible to get the 3 feet of separation from the bottom of an infiltration practice to the seasonal high water table REQUIRED under the NPDES [Construction General Permit](http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.html). Non-infiltration BMPs, such as lined filtration or settling practices, should be considered in areas with shallow groundwater.

2.2.2 Why is Shallow Groundwater a Concern?

Removal of some pollutants (e.g., bacteria) can occur in the vadose zone beneath the base of the BMP. Pollutant removal in the vadose zone is attained via biological activity, chemical degradation, adsorption of pollutants to soil, and plant uptake. Shallow groundwater reduces the depth of the unsaturated soil available for treatment, leading to an increased likelihood of groundwater contamination. The vadose zone is further reduced when a groundwater mound forms. These sites present challenges to stormwater management, however these challenges can be managed. General guidelines for investigation and management are presented in the following sections

2.2.3 How to Investigate for Shallow Groundwater

Investigations are recommended for all proposed stormwater facilities located on sites with a suspected shallow groundwater table. The investigation should be two-fold. First, appropriate screening tools such as soil surveys, geologic atlases, or well records should be used to determine the likelihood that the groundwater table is shallow. If a shallow groundwater table is present, a geotechnical investigation should be conducted.

Geotechnical investigations are recommended for all proposed stormwater facilities located on sites where it is suspected that the 3 foot vertical separation between the base of the BMP and the groundwater table might not be achievable. This is needed to show that permit requirements have been met. The guidelines for how to investigate for shallow groundwater are summarized in **Table 2.2**; however, these guidelines should not be interpreted as all-inclusive. The size and complexity of the project will drive the extent of any subsurface investigation. Regardless of the results of the initial site screening, soils borings and infiltration tests should be performed to verify site soil conditions.

2.2.4 What are General Stormwater Management Guidelines for Areas with Shallow Groundwater?

The following investigations and design variants are HIGHLY RECOMMENDED for infiltration BMPs proposed to be located in areas of shallow groundwater:

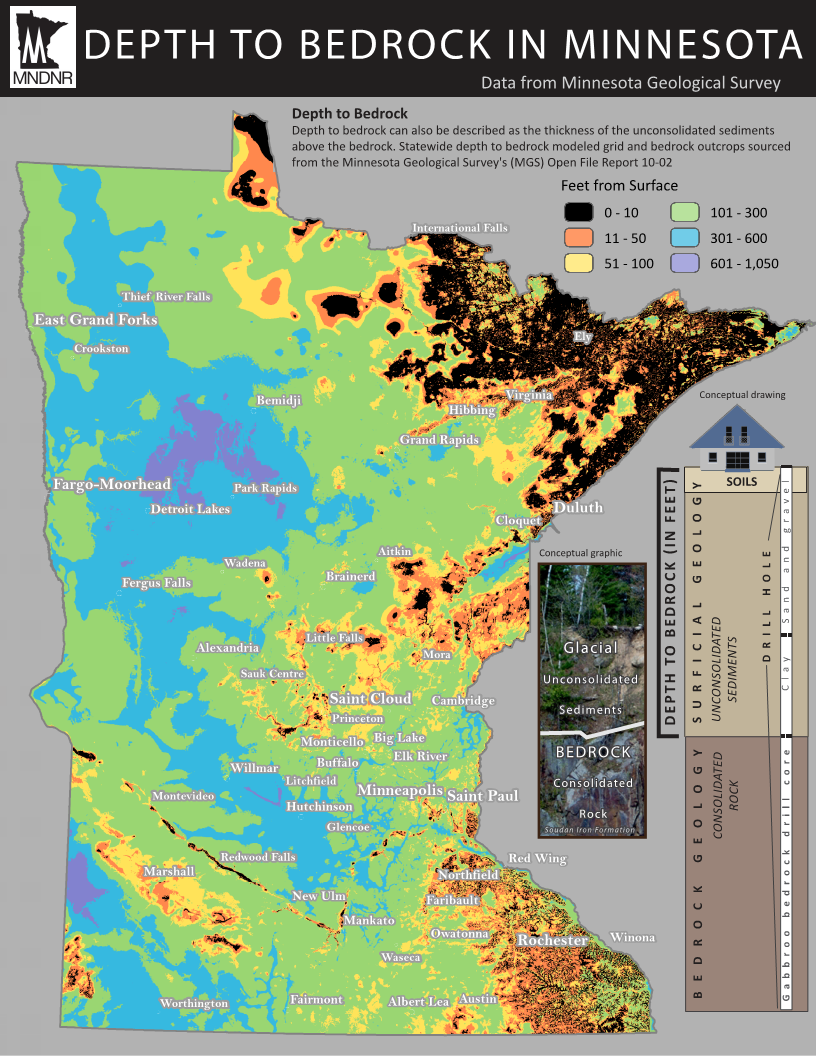
* **Conduct thorough geotechnical investigations with geotechnical analyses** similar to those recommended for Karst regions.
* **Conclude the site to be infeasible for infiltration BMPs where a minimum 3 foot separation between the bottom of the BMP and groundwater cannot be achieved.** The CGP prohibits infiltration BMPs when the separation distance is less than 3 feet.
* **Consider stormwater wetlands** **which require a shallower ponding depth than stormwater ponds.** The disadvantage of stormwater wetlands is that the shallow depth of the wetlands often creates footprints that are larger than ponds.
* **Consider a stormwater pond that will intercept the groundwater table.** This approach requires close examination of the land uses to assess the potential for stormwater hotspot or other highly concentrated runoff sources that would contribute excess pollutants to the groundwater. If a stormwater hotspot is identified as a contributor, then it is the recommendation of the MPCA that the pond include a liner to protect against groundwater contamination.

MPCA is often asked why it allows a sedimentation pond (no liner) to be constructed that may intercept the water table, but require a minimum of 3 feet of separation from the bottom of any constructed infiltration practice and the water table. The treatment processes for these two practices are very different and may help to explain the requirements. A stormwater pond achieves pollutant removal through the process of settling of suspended solids. If the basin is large enough, contains vegetation, and has a long detention time, additional treatment through biological uptake and microbial action can also occur. An infiltration practice removes pollutants through filtering that occurs in the minimum 3 foot unsaturated soil layer beneath the practice along with the biologic and microbial activity that takes place in the layer under aerobic conditions.

* 1. Shallow Depth to Bedrock

2.3.1 What is Shallow Depth to Bedrock?

Sites with shallow bedrock are defined as sites having bedrock within 6 feet or less of the ground surface.. Shallow bedrock is found in many portions of the state, but is a particular problem in the northeastern region (**Figure 2.2**). When installing an infiltration BMP, there must be at least 3 feet of separation between the base of the BMP and the bedrock per the [Minnesota CGP](http://stormwater.pca.state.mn.us/index.php/Construction_stormwater_permit). Bedrock at the 6 foot depth is a trigger to perform a geotechnical investigation to determine the location of the bedrock in the area in and around the proposed BMP to ensure that the 3 foot separation can be achieved.



**Figure 2.2 Bedrock Outcroppings Areas in Northern Minnesota** (Source: MN DNR, with permission. Map is from the Minnesota DNR Lands and Minerals Division and depth to bedrock grid data is from the Minnesota Geological Survey)

2.3.2 Why is Shallow Depth to Bedrock a Concern?

Shallow bedrock impacts the depths of pond/basin BMPs and impacts the depth of subsurface for infiltration BMPs. These sites present challenges to stormwater management, however these challenges can be managed. General guidelines for investigation and management are presented below. Special caution for steep slopes and fractured bedrock is urged.

2.3.3 How to Investigate for Shallow Bedrock

It is important to understand the general depth to bedrock over the entire site, but more specifically it is important to know the depth to bedrock in and around the area of the proposed BMP. Geotechnical investigations are recommended for all proposed stormwater facilities located in regions with shallow bedrock. The purpose of the investigation is to identify subsurface conditions which can pose an environmental concern or a construction hazard to a proposed stormwater management practice. The guidelines for how to investigate for shallow bedrock are summarized in **Table 2.2**; however, these guidelines should not be interpreted as all-inclusive. The size and complexity of the project will drive the extent of any subsurface investigation.

2.3.4 What are General Stormwater Management Guidelines for Areas with Shallow Bedrock?

The following investigations and guidelines are HIGHLY RECOMMENDED for infiltration and other BMPs proposed to be located in areas with shallow depth to bedrock:

* **Conduct thorough geotechnical investigations in areas with suspected or documented shallow bedrock.** Perform site geotechnical analysis similar to karst.
* **Consider a non-infiltration BMP or moving the BMP to a location on site with sufficient depth to bedrock if the required 3-foot separation cannot be achieved**. It may be possible to move the infiltration BMP to another location in order to achieve this separation.
* **Consider shallow ponding depths up to 12 inches** for filters, swales, and bioretention.
* **Conclude that infiltration of stormwater runoff from stormwater hotspots is not feasible** due to potential for connections with bedrock fracture zones.
* **Consider stormwater wetlands which have shallower ponding depths than stormwater ponds.** The disadvantage is that the shallow depths result in basins with large footprints which may not be feasible on small sites.

**Table 2.3** provides an overview of shallow bedrock and soil related design considerations for different structural practice groups.

Table 2.3 Recommendation for Structural BMP use in Settings with Shallow Depth to Bedrock. The CGP requires a liner for bioretention, media filter, vegetative filter, and infiltration trench/basins if 3 feet is not present between practice bottom and bedrock.

|  |  |
| --- | --- |
| BMP | Shallow depth to bedrock considerations |
| Bioretention | * Should be lined and constructed with an underdrain if minimum separation distance of 3 feet is not present between practice bottom and bedrock. |
| Media filter | * Recommended practice in areas of shallow bedrock. * Can be located in bedrock, but will be expensive due to blasting and requires lining. |
| Vegetative filter | * Recommended practice in areas of shallow bedrock. * Dry swales with engineered soil media will need lining and an underdrain if minimum separation distance of 3 feet is not present between practice bottom and bedrock. |
| Infiltration trench or basin | * Will be limited due to minimum separation requirement. Surface area to depth ratios of practices may need to be larger. Arch pipe and other perforated storage "vault" practices can help increase treatment volumes within limited spaces. Liners may be needed * If used, should have supporting geotechnical investigations and calculations * Avoid in areas with stormwater hotspots. * Pre-treatment should be extensive to limit risk of groundwater contamination if groundwater is close to the land surface. * Local review authority should be consulted for approval. |
| Stormwater ponds | * Will have depth limitation to consider, making surface areas larger for a given storage volume. * Shallower depths may be undesirable from an aesthetic standpoint, particularly if wide fluctuations in water level are expected. However, permit requirements state that the minimum depth must be at least 3 feet deep. * Bedrock should act like a liner and help to maintain a permanent pool, unless fracture zone is present. |
| Constructed wetlands | * Applied more easily than ponds, but will also require larger surface area to drainage area ratios. * Bedrock should act like a liner and help to maintain a permanent pool, unless fracture zone is present |
| Source: <http://stormwater.pca.state.mn.us/index.php/BMP_use_in_settings_with_shallow_soils_and_shallow_depth_to_bedrock> | |

* 1. Soils with Low Infiltration Capacity

2.4.1 What are Soils with a Low Infiltration Capacity?

Soils with low [infiltration](http://stormwater.pca.state.mn.us/index.php/Glossary#I) capacity are defined as soils with steady-state infiltration rates equal to or less than 0.06 inches per hour. County soil surveys are useful for initial screening to identify soils that may have low infiltration rates. Most county soil surveys are [available digitally](http://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=MN) from the NRCS (National Resources Conservation Service). These surveys are not accurate enough to determine site-specific characteristics suitable for infiltration systems, so a [detailed site analysis](#Investigation) should be performed for all proposed infiltration BMPs (Susilo, 2009).

Stormwater management limitations in areas with low infiltration capacity soils generally preclude large-scale infiltration. These soils will typically be categorized under [Hydrologic Soil Group](http://stormwater.pca.state.mn.us/index.php/Glossary#H) (HSG) D. Design infiltration rates for these soils are conservative estimates of long-term, sustainable infiltration rates that have been documented in Minnesota. They are based on in-situ measurement within existing infiltration practices in Minnesota, rather than national numbers or rates based on laboratory columns.

The [CGP prohibits](http://stormwater.pca.state.mn.us/index.php/III._STORMWATER_DISCHARGE_DESIGN_REQUIREMENTS#III.D._PERMANENT_STORMWATER_MANAGEMENT_SYSTEM) infiltration when an infiltration system will be constructed in areas of predominately Hydrologic Soil Group D (clay) soils unless allowed by a local unit of government with a current MS4 permit.

2.4.2 Why are Soils with a Low Infiltration Capacity a Concern?

Sites with low infiltration capacity soils may limit the type, location, number and/or sizing of infiltration BMPs that can be used for stormwater management. Low infiltration rates result in extended surface ponding of water, which may damage vegetation, lead to mosquito breeding, damage soil structure, and reduce pollutant treatment by the BMP. Certain watershed organizations in Minnesota do not allow the use, or strongly discourage the use, of infiltration BMPs where soil infiltration capacity is low. This does not mean, however, that these soils do not have any infiltration and recharge capabilities. It may be possible for sites to partially or fully meet infiltration objectives as long as appropriate design modifications have been incorporated, such as amending the soil with compost or sand, or incorporating an underdrain into the practice.

2.4.3 How to Investigate Soils with Low Infiltration Capacity

Soil tests to determine infiltration capacity of soil should be performed at all proposed stormwater facilities that plan to have a recharge or infiltration component to their design. The purpose of the testing is to identify and confirm the soil characteristics and determine suitability, if any, for [infiltration](http://stormwater.pca.state.mn.us/index.php/Glossary#I) BMPs. The guidelines for how to investigate for low capacity soils are summarized in **Table 2.2**; however, these guidelines should not be interpreted as all-inclusive. The size and complexity of the project will drive the extent of any subsurface investigation.

2.4.4 What are General Stormwater Management Guidelines for Sites with Low Infiltration Capacity Soils?

* **Local soil surveys should be used for preliminary determination of infiltration capacity** of the soils on site; If the soil survey suggests soils with very low infiltration capacities, then alternative BMPs such as swales, filters, etc. should be considered. If the survey suggests the potential for infiltration, the on-site soil testing should be done to accurately characterize site soils. The testing should be conducted in the most restrictive layer of soil that is found within 5-feet below the bottom of the proposed BMP.
* **Soil**[**compost amendments**](http://stormwater.pca.state.mn.us/index.php/Turf)**should be considered for lawns and other pervious surfaces to increase pervious area storage and/or decrease pervious surface runoff.** Designers should also consider disconnection of impervious surfaces, by draining rooftops and other impervious surface runoff to compost amended pervious surfaces before collection and discharge into a structural BMP.
* **Where volume reduction is a primary objective for a site (e.g., required by permit, potentially a receiving water-based goal due to channel erosion, nuisance flooding, or inadequate infrastructure capacity), emphasis should be placed on practices that promote runoff**[**reuse**](http://stormwater.pca.state.mn.us/index.php/Stormwater_re-use_and_rainwater_harvesting)**and evapotranspiration** such as cisterns, rain barrels, [green roofs](http://stormwater.pca.state.mn.us/index.php/Green_roofs), evaporative systems, and biofiltration in order to maximize volume reduction.
* **A mounding analysis should be conducted to ensure that any groundwater mound that develops under a BMP will not extend into the BMP.** This mounding analysis is especially important for soils with low permeability since such soils cannot efficiently dissipate groundwater through the soil column.

The following table, **Table 2.4,** provides an overview of low infiltration capacity soil related design considerations for several structural BMPs.

Table 2.4 Structural BMP use in Soil with Low Infiltration Capacity

|  |  |
| --- | --- |
| BMP | Low Infiltration Capacity Soil Considerations |
| Bioretention | Should be constructed with an underdrain. Recharge criteria, if applicable, can be met by modifying the design to include an infiltration gallery below the underdrain, so long as it is appropriately sized. |
| Media filter | Recommended practice. Some design variants can be modified to incorporate an infiltration gallery that can help meet recharge criteria, if properly sized. |
| Vegetative filter | Recommended practice |
| Infiltration trench or basin | Not recommended  Soils analysis should be conducted to confirm limiting aspects of soil profile. |
| Stormwater ponds | Acceptable practice since the soils will help maintain a permanent pool. |
| Constructed wetlands | Acceptable practice since the soils will help marinating a permanent pool if the practice is not tied into the groundwater table.  Compost amendments may be necessary to establish a suitable planting bed. |
| Source: MPCA Stormwater Manual | |

**Table 2.2 How to Investigate for Certain Site Conditions that Create Constraints on Stormwater Infiltration**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Shallow Groundwater** | **Shallow Bedrock** | **Soils with Low Infiltration Capacity** | **Karst** |
| Preliminary site investigation | NA | NA | NA | The level of detail required will depend on the likelihood that karst is present and any local regulations. The preliminary site investigation should include, but not be limited to (Pennsylvania BMP, 2009):   * A review of aerial photographs, geological literature, sinkhole maps, previous soil borings, existing well data, and municipal wellhead or aquifer protection plans. * A site reconnaissance, including a thorough field examination for features such as limestone pinnacles, sinkholes, closed depressions, fracture traces, faults, springs, and seeps. * The site should be observed under varying weather conditions, especially during heavy rains and in different seasons to identify and map any natural drainageways. |
| Subsurface material investigation | The investigation is designed to determine the nature and thickness of subsurface materials, including depth to bedrock and to the water table. Subsurface data for depth to groundwater may be acquired by soil boring or studying existing wells on the site, if present. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of the groundwater formations under the surface. The data listed below should be acquired under the direct supervision of a qualified geologist, geotechnical engineer, or soil scientist who is experienced in conducting such studies. Pertinent site information should include the following:   * Known groundwater depth or bedrock characteristics (type, geologic contacts, faults, geologic structure, rock surface configuration) * Soil characteristics (type, thickness, mapped unit) * Bedrock outcrop areas | The investigation is designed to determine the nature and thickness of subsurface materials, including depth to bedrock and to the water table. Subsurface data for depth to groundwater may be acquired by soil boring or backhoe investigation. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of the groundwater formations under the surface. The data listed below should be acquired under the direct supervision of a qualified geologist, geotechnical engineer, or soil scientist who is experienced in conducting such studies. Pertinent site information should include the following:   * Known groundwater depth or bedrock characteristics (type, geologic contacts, faults, geologic structure, rock surface configuration) * Soil characteristics (type, thickness, mapped unit) * Bedrock outcrop areas | Soil testing is recommended for all proposed stormwater facilities that plan to have a recharge or infiltration component to their design. Testing can be less rigorous than that for karst areas or sites with shallow bedrock and groundwater. The investigation is designed to identify and confirm the soil characteristics and determine their suitability, if any, for infiltration practices. | The investigation should determine the nature and thickness of subsurface materials, including depth to bedrock and the water table. Subsurface data may be acquired by backhoe excavation and/or soil boring. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of karst formations under the surface. This is an iterative process that might need to be repeated until the desired detailed knowledge of the site is obtained and fully understood. The data listed below should be acquired under the direct supervision of a qualified and experienced karst scientist. Pertinent site information to collect includes the following:   * Bedrock characteristics (ex. type, geologic contacts, faults, geologic structure, rock surface configuration) * Depth to the water table and depth to bedrock * Type and percent of coarse fragements * Soil characteristics (ex. color, type, thickness, mapped unit, geologic source/history) * Photo-geologic fracture trace map * Bedrock outcrop areas * Sinkholes and/or other closed depressions * Perennial and/or intermittent streams, and their flow behavior (ex. a stream in a karst area that loses volume could be a good indication of sinkhole infiltration) |
| Location of Soil Borings | Borings should be located in order to provide representative area coverage of the proposed BMP facilities. The location of borings should be:   * Within each distinct major soil type present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records. * Next to bedrock outcrop areas and/or in areas with known shallow groundwater if present. * Near the edges and center of the proposed practice and spaced at equal distances from one another. * Near any areas identified as anomalies from any existing geophysical studies. | Borings should be located in order to provide representative area coverage of the proposed BMP facilities. The location of borings should be:   * Within each distinct major soil type present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records. * Next to bedrock outcrop areas and/or in areas with known shallow groundwater if present. * Near the edges and center of the proposed practice and spaced at equal distances from one another. * Near any areas identified as anomalies from any existing geophysical studies. | Borings should be located in order to provide representative area coverage of the proposed BMP facilities. The location of borings should be:   * Within each distinct major soil type present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records. * Near the edges and center of the proposed practice and spaced at equal distances from one another. * Near any areas identified as anomalies from any existing geophysical studies. | The local variability typical of karst areas could mean that a very different subsurface could exist close by, perhaps as little as 6 inches away. To accommodate this variability, the number and type of borings must be carefully assessed. If the goal is to locate a boring down the center of a sinkhole, the previous geophysical tests or excavation results can show the likely single location to achieve that goal. If the goal is to “characterize” the entire site, then an evaluation needs to occur to determine the number and depth needed to adequately represent the site. Again, the analyst must acknowledge the extreme variability and recognize that details can easily be missed. Some general guidance for locating borings include:   * Getting at least 1 boring in each distinct major soil type present, as mapped by the MGS and USGS and local county records. * Placing an adequate number as determined by a site investigation near on-site geologic or geomorphic indications of the presence of sinkholes or related karst features. * Locating along photo-geologic fracture traces. * Locating adjacent to bedrock outcrop areas. * Locating a sufficient number to adequately represent the area under any proposed stormwater facility. * Documenting any areas identified as anomalies from any existing geophysical or other subsurface studies. |
| Number of Soil Borings | The number of recommended borings is described below.   * Infiltration trenches, bioretention, and filters - a minimum of 2 per practice. * Ponds/wetlands - a minimum of 3 per practice, or 3 per acre, whichever is greater. * Additional borings – as needed to define lateral extent of limiting horizons, or site specific conditions, where applicable. | The number of recommended borings is described below.   * Infiltration trenches, bioretention, and filters - a minimum of 2 per practice. * Ponds/wetlands - a minimum of 3 per practice, or 3 per acre, whichever is greater. * Additional borings – as needed to define lateral extent of limiting horizons, or site specific conditions, where applicable. | The number of recommended borings is described below.   * Infiltration trenches, bioretention, and filters - a minimum of 2 per practice. * Ponds/wetlands - a minimum of 3 per practice, or 3 per acre, whichever is greater. * Additional borings – as needed to define lateral extent of limiting horizons, or site specific conditions, where applicable. | The number and depth of borings will depend entirely upon the results of the subsurface evaluation obtained from the observational, geophysical, and excavation studies, as well as other borings. There are no prescriptive guidelines to determine the number and depth of borings. These will have to be determined by the qualified staff conducting the BMP management evaluation and will be based upon the data needs of the installation. The borings must extend well below the bottom elevation of the designed BMP, however, to make sure that there are no karst features that will be encountered or impacted as a result of the installation. |
| Depth of Soil Borings | Borings should be extended to a minimum depth of 5 feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered. | Borings should be extended to a minimum depth of 5 feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered. | Borings should be extended to a minimum depth of 5 feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered. | The number and depth of borings will depend entirely upon the results of the subsurface evaluation obtained from the observational, geophysical, and excavation studies, as well as other borings. There are no prescriptive guidelines to determine the number and depth of borings. These will have to be determined by the qualified staff conducting the BMP management evaluation and will be based upon the data needs of the installation. The borings must extend well below the bottom elevation of the designed BMP, however, to make sure that there are no karst features that will be encountered or impacted as a result of the installation. At least 1 subsurface cross section should be provided for the BMP installation, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed installation, using the actual geophysical and boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data. |
| Identification of Material | All material penetrated by the boring should be identified, as follows:   * Provide descriptions, logging, and sampling for the entire depth of the boring. * Note any stains, odors, or other indications of environmental degradation. * Perform a laboratory analysis of a minimum of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. * Identify soil characteristic including, at a minimum: color; mineral composition; grain size, shape, and sorting; and saturation. * Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed (sticky clay soils typically found in waterlogged soils). * Measure water levels in all borings at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements. * Estimate soil engineering characteristics, including “N” or estimated unconfined compressive strength, when conducting a standard penetration test (SPT). | All material penetrated by the boring should be identified, as follows:   * Provide descriptions, logging, and sampling for the entire depth of the boring. * Note any stains, odors, or other indications of environmental degradation. * Perform a laboratory analysis of a minimum of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. * Identify soil characteristic including, at a minimum: color; mineral composition; grain size, shape, and sorting; and saturation. * Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed (sticky clay soils typically found in waterlogged soils). * Measure water levels in all borings at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements. * Estimate soil engineering characteristics, including “N” or estimated unconfined compressive strength, when conducting a standard penetration test (SPT). | All material penetrated by the boring should be identified, as follows:   * Provide descriptions, logging, and sampling for the entire depth of the boring. * Note any stains, odors, or other indications of environmental degradation. * Perform a laboratory analysis of a minimum of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. * Identify soil characteristic including, at a minimum: color; mineral composition; grain size, shape, and sorting; and saturation. * Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed (sticky clay soils typically found in waterlogged soils). * Measure water levels in all borings at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements. | All material identified by the excavation and geophysical studies and penetrated by the boring should be identified, as follows:   * Provide descriptions, logging, and sampling for the entire depth of the boring. * Note any stains, odors, or other indications of environmental degradation. * Perform laboratory analysis on a of 2 soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions. * Identify soil characteristics including, as a minimum: color; mineral composition; grain size, shape, sorting and degree of saturation. * Log any indications of water saturation to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed should be provided. Be aware that ground water levels in karst can change dramatically in short periods of time and will not necessarily leave mottled or gleyed evidence. * Record water levels in all borings over a time-period reflective of anticipated water level fluctuation. That is, water levels in karst geology can vary dramatically and rapidly. The boring should remain fully open to a total depth reflective of these variations and over a time that will accurately show the variation. Be advised that to get a complete picture, this could be a long-term period. Measurements could of course be collected during a period of operation of a BMP, which could be adjusted based on the findings of the data collection. * Report an estimation of soil engineering characteristics including “N” or estimated unconfined compressive strength, when conducting a SPT |
| Evaluation of Findings | At least 1 figure showing the subsurface soil profile cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data. | At least 1 figure showing the subsurface soil profile cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data. | N A | At least 1 figure showing the subsurface soil profile cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data. |
| Infiltration Rate Testing |  |  | Soil permeability should be determined in the field using the following procedure (MDE, 2000), or an accepted alternative method.   * Install casing (solid 6-inch diameter) to 36 inches below proposed BMP bottom. * Remove any smeared soiled surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester’s discretion, a 2 inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring. Fill casing with clean water to a depth of 36 inches and allow to pre-soak for up to 24 hours. * Refill casing with another 36 inches of clean water and monitor water level (measured drop from the top of the casing) for 1 hour. Repeat this procedure (filling the casing each time) 3 additional times, for a total of 4 observations. Upon the tester’s discretion, the final field rate may either be the average of the 4 observations, or the value of the last observation. The final rate should be reported in inches per hour. * May be done through a boring or open excavation that is protected from access by the public. * The location of the test should correspond to the BMP location.   Upon completion of the testing, the casings should be immediately pulled, and the test pit should be back-filled. |  |
| Geophysical and Dye Techniques |  |  |  | Stormwater managers in need of subsurface geophysical surveys are encouraged to obtain the services of a qualified geophysicist experienced in karst geology. Some of the geophysical techniques available for use in karst terrain include: seismic refraction, ground-penetrating radar, and electric resistivity. The surest way to determine the flow path of water in karst geology is to inject dye into the karst feature (sinkhole or fracture) and watch to see where it emerges, usually from a spring. The emergence of a known dye from a spring grants certainty to a suspicion that ground water moves in a particular pattern. Dye tracing can vary substantially in cost depending upon the local karst complexity, but it can be a reasonably priced alternative, especially when the certainty is needed. |

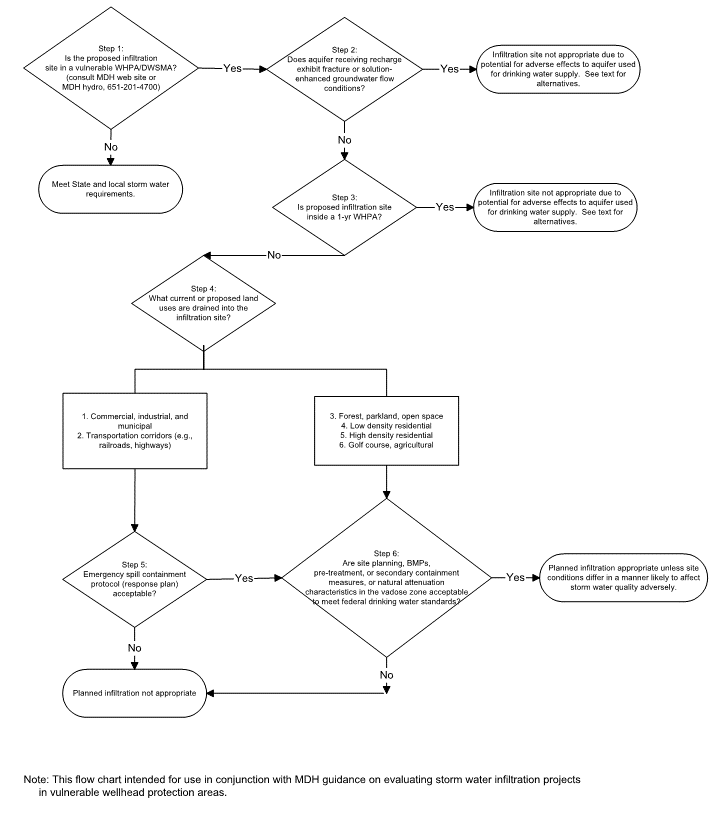
* 1. Zoning Restrictions

2.5.1 Wellhead Protection Areas

A Wellhead Protection Area (WHPA) is the recharge area for a public supply well. The Wellhead Protection Program is administered by the Minnesota Department of Health (MDH). Wellhead protection planning is largely a local activity in Minnesota. Individual public water supply systems decide how to manage land use within WHPAs. WHPAs are managed to safeguard the drinking water supply.

WHPA boundaries are defined and a vulnerability assessment is included in wellhead protection plans, available from the Wellhead Protection Manager at the public water supplier or from MDH staff. Stormwater infiltration within a WHPA is not recommended if the aquifer receiving the water from the proposed stormwater BMP exhibits fracture or solution-enhancing groundwater flow conditions.

The MDH has laid out a [six-step process](http://www.health.state.mn.us/divs/eh/water/swp/stormwater.pdf) for evaluating proposed stormwater infiltration projects in vulnerable wellhead protection areas. The process is summarized using the following flowchart (**Figure 2.3)**.



**Figure 2.3 Flow Chart for Evaluating Proposed Stormwater Infiltration Projects in Areas with Vulnerable Groundwater** (Source: Minnesota Department of Health, with permission, 2007)

Infiltration of stormwater within WHPAs is not recommended in such settings, especially if karst features exist. Infiltration BMPs are not appropriate in the following situations:

* **The proposed stormwater infiltration site is within the 1 year time of travel** (known as the emergency response zone) as designated by MDH.
* **Sites where predominant land uses upgradient of the proposed infiltration site contain contaminants generated by PSHs**; additional information about PSHs can be found [here](#PSH). Dependent on the upgradient land uses, emergency procedures for containment of spills must be established and acceptable.

For stormwater infiltration practices in WHPAs, the water exiting the infiltration device and recharging the groundwater system should meet federal drinking water quality standards.

Additional recommendations on managing stormwater in source water protection areas are available from the USEPA in the document titled [Managing Stormwater Runoff to Prevent Contamination of Drinking Water](http://www.epa.gov/safewater/sourcewater/pubs/fs_swpp_stormwater.pdf).

2.5.2 Shoreland Zones

Regulation of infiltration BMPs may be subject to local shoreline ordinances, found at the local city or county zoning offices, as well as the local watershed management organization or soil and water conservation district. Additional regulations can be found under [Minnesota Administrative Rules Part 6120.3300 Subpart 11](https://www.revisor.mn.gov/rules/?id=6120.3300). The [Minnesota Administrative Rules](https://www.revisor.mn.gov/rules/?id=6120.3300) that govern shoreland zones includes a section on stormwater management. These Rules encourage the utilization of natural features for the management of stormwater, including infiltration. Traditional conveyance of stormwater runoff through storm sewers is discouraged.

* 1. Karst

Karst geology makes up approximately 20 percent of the land surface in the United States. It is also found in other parts of the world such as China, Europe, the Caribbean, Australia, and Madagascar ([USGS, N.D.](http://water.usgs.gov/ogw/karst/index)). Karst regions in Minnesota are predominantly found in the southeastern portion of the state (**Figure 2.4**). Use of infiltration BMPs in karst regions can be complicated and necessitates additional requirements for geotechnical testing, pre-treatment of stormwater runoff, and ponding of runoff. Caution must be used in interpreting the geographic depiction of karst lands as subsurface conditions can change rapidly over very short distances (Karst Working Group, 2009). In general, generalized maps of active karst will be less accurate than a county-scale map. The following county-level maps have been developed.

Olmstead: [Sinkholes and sinkhole probability](http://conservancy.umn.edu/bitstream/handle/11299/58436/sinkholes%5B1%5D.pdf?sequence=4&isAllowed=y)

Wabasha: [Karst features](http://conservancy.umn.edu/bitstream/handle/11299/58557/plate5%5B1%5D.pdf?sequence=5&isAllowed=y)

Fillmore: [Sinkholes and sinkhole probability](http://files.dnr.state.mn.us/waters/groundwater_section/mapping/cga/c08_fillmore/pdf_files/plate08.pdf)

Goodhue: [Sinkholes, sinkhole probability, and springs and seeps](http://files.dnr.state.mn.us/waters/groundwater_section/mapping/cga/c12_goodhue/pdf_files/plate10.pdf)

Winona: [Sinkhole probability](http://reflections.mndigital.org/cdm/ref/collection/mgs/id/623) (or [link here](https://server16022.contentdm.oclc.org/cdm4/item_viewer.php?CISOROOT=/mgs&CISOPTR=623&CISOBOX=1&REC=3))

Mower: [Karst hydrogeomorphic units](http://files.dnr.state.mn.us/waters/groundwater_section/mapping/cga/c11_mower/pdf_files/plate10.pdf)

Pine: [Sinkhole distribution](http://conservancy.umn.edu/bitstream/handle/11299/58554/plate6%5B2%5D.pdf?sequence=4&isAllowed=y)



**Figure 2.4 Minnesota karst lands** (Source: E. Calvin Alexander, University of Minnesota, with permission)

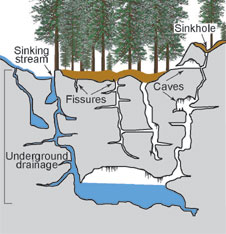
In Minnesota there are three classifications of karst lands (See **Figure 2.4)**:

* **Active Karst.** Active karst is defined as areas underlain by carbonate bedrock with less than 50 feet of sediment cover.
* **Transition Karst.** Transition karst is defined as areas underlain by carbonate bedrock with 50 to 100 feet of sediment cover.
* **Covered Karst.** Covered karst is defined as areas underlain by carbonate bedrock but with more than 100 feet of sediment cover.

A site with Active Karst has the greatest potential for development of a sinkhole below a BMP and the recommendations contained in this section should be considered for all proposed BMPs. For Transitional Karst sites, it is HIGHLY RECOMMENDED that the nature of the overlaying soils should be evaluated with respect to the potential for catastrophic failure given the increase in hydrostatic pressure created by a BMP.

2.6.1 What is Karst?

Karst is a landscape formed by the dissolution of a layer or layers of soluble bedrock. The bedrock is usually carbonate rock such as limestone or dolomite but the dissolution has also been documented in weathering resistant rock, such as quartz. The dissolution of the rocks occurs due to the reaction of the rock with acidic water. Rainfall is already slightly acidic due to the absorption of carbon dioxide (CO2), and becomes more so as it passes through the subsurface and picks up even more CO2. As the runoff passes through the subsurface and reacts with the rocks, cracks and fissures forms (**Figure 2.5**). These cracks and fissures grow, creating larger passages, caves, and may even form sinkholes as more and more acidic water infiltrates into the subsurface ([American Rivers, N.D.)](http://www.eahcp.org/files/uploads/09-03-10Attachment4aUsing_Green_Infrastructure.pdf).



**Figure 2.5 The features of a karst system** (Source: The University of South Texas at Austin – permission pending).

Subterranean drainage through karst geology limits the presence of surface water in places, explaining the absence of rivers and lakes. Many karst regions display distinctive surface features such as a sinkhole or natural pit (often termed cenotes or dolines), fissures, or caves ([USGS, N.D.](http://water.usgs.gov/ogw/karst/pages/whatiskarst)). However, distinctive karst surface features may be completely absent where the soluble rock is below a deep layer of glacial debris (termed mantled), or is below one or more layers of non-soluble rock strata. Some karst regions include thousands of caves, although evidence of caves large enough for human exploration is not a required characteristic of karst.

Knowledge of the presence of sinkholes is an absolute indication of active karst. In these cases, an easement or reserve area should be identified on the development plans for the project so that all future landowners know of the presence of active karst on their property.

Additional information on karst in Minnesota can be found at the following sources:

[Karst in Minnesota](http://www.pca.state.mn.us/index.php/water/water-types-and-programs/groundwater/groundwater-basics/karst-in-minnesota.html) – Minnesota Pollution Control Agency

[Karst features in Minnesota](http://www.mngs.umn.edu/indx.html) – Minnesota Geologic Survey

[The Development of a Karst Feature Database for Southeastern Minnesota](http://caves.org/pub/journal/PDF/V64/v64n1-Goa.pdf) – Alexander and Tipping

2.6.2 Why is Karst Geology a Concern?

Infiltration BMPs in karst settings have the potential of creating sinkholes as a result of the additional weight of water in a structural BMP (termed hydraulic head) and/or water infiltrated from the BMP that can dissolve the carbonate rock (e.g., limestone). These conditions can lead to the erosion of bedrock (**Figures 2.6** and **2.7**) underneath or adjacent to a BMP. In addition, the pollutants being carried by the stormwater runoff can pass rapidly through the subsurface into the groundwater, creating a greater risk of groundwater contamination than is found in other soil types. **Where karst conditions exist, there are no prescriptive rules or universally accepted management approaches because the subsurface conditions and subsurface drainage pattern variability intrinsic to karst geology.**



**Figure 2.6** **A collapsed karst feature where a stormwater pond previously existed. The site was in Woodbury, Minnesota** (Source: Mike Trojan, 2013)



**Figure 2.7 Woodbury sinkhole collapse looking towards the south** (Source: Mike Trojan, 2013)

In general when underlying karst is known or suspected to be present at the site, stormwater runoff should not be concentrated and discharged into or near known sinkholes. Instead, the runoff should be

* dispersed;
* pretreated and then infiltrated, only if subsurface investigations and geotechnical analysis confirm that there are no unstable zones below the BMP;
* perhaps additional borings and deeper ones to target evaluation of transitional karst zone.  Once ponds are constructed, you could include contingency plans for cases where karst features open up and impact a pond.  Basically, you would conduct geotechnical borings to appropriate depths trying to identify unstable zones, then target those zones for grouting;
* conveyed to a collection and transmission system away from the area via vegetated drainageways.

See a detailed discussion of guidelines in **Section 2.6.4**.

2.6.3 How to Investigate for Karst on a Site

Developers, communities, public works agents, and other stormwater managers should conduct site investigations prior to designing and implementing stormwater BPMs in both Active and Transitional Karst areas. A site with Active Karst has the greatest potential for development of a sinkhole below a BMP and the recommendations contained in this section should be considered for all proposed BMPs. For Transitional Karst sites, it is HIGHLY RECOMMENDED that the nature of the overlaying soils should be evaluated with respect to the potential for catastrophic failure given the increase in hydrostatic pressure created by a BMP. The level of investigation required will depend on the likelihood of karst being present and the regulatory requirements in the area.

The purpose of the investigation is to identify subsurface voids, cavities, fractures, or other discontinuities which could pose an environmental concern or a construction hazard to an existing or proposed stormwater management facility. Of special concern are the construction hazards posed by karst geology, the formation of sinkholes, and the possibility of a preferential pathway that would provide a direct route for polluted runoff to enter the regional groundwater system. Because of the complexity inherent to active and transitional karst areas, there is no single set of investigatory guidelines that works for every location. Typically, however, the first step is a preliminary investigation that involves analyzing geological and topographic county maps, and aerial photography to determine if active karst is known to be present. Included in the preliminary investigation should be a site visit to perform a visual observation for karst features such as sinkholes. Results of the investigation should be reported to the appropriate agency, including the Department of Natural Resources (DNR), Minnesota Geological Survey (MGS), and local agencies (such as the city, township or county). These known and discovered karst features should be surveyed for specific location and permanently recorded on the property deed.

If it is determined that active karst is present, a detailed site investigation, including a subsurface materials investigation should be conducted. The design of any geotechnical investigation should reflect the size and complexity of the proposed project, as well as the local knowledge of the threat posed by the karstic geology. The geotechnical investigation should first assess the subsurface heterogeneity (variability). With this information in-hand, borings or observation wells can then be accurately installed to obtain vertical data surrounding or within karst features or within areas of instability that have the potential for development of karst. The vertical data should be used to determine the nature and thickness of the subsurface materials and needs to include information involving depth to the bedrock and depth to the groundwater table. The investigation will be an iterative process and should be expanded until the desired detailed knowledge of the site is obtained and fully understood (Karst Working Group, 2009). **Table 2.2** describes general guidance that may be used depending upon the local situation and information deemed as needed. Information in the table should not be interpreted as all-inclusive.

Additional information regarding site investigations in karst areas can be found in [Appendix B](http://tnpermanentstormwater.org/manual/27%20Appendix%20B%20Stormwater%20Design%20Guidelines%20for%20Karst%20Terrain.pdf) of the [Tennessee Permanent Stormwater Management and Design Guidance Manual](http://tnpermanentstormwater.org/manual.asp) (Tennessee Department of Environment and Conservation, 2014). This manual provides a chart which will guide designers through the investigative process and will help designers determine if any special analysis is required.

2.6.4 What are General Stormwater Management Guidelines for Karst Areas?

REQUIRED – The [Construction Stormwater Permit](http://stormwater.pca.state.mn.us/index.php/III._STORMWATER_DISCHARGE_DESIGN_REQUIREMENTS#III.D._PERMANENT_STORMWATER_MANAGEMENT_SYSTEM) prohibits infiltration of stormwater runoff “within 1,000 feet up-gradient or 100 feet down-gradient of active karst features unless allowed by a local unit of government with a current MS4 permit”. These guidelines provide stormwater management procedures for determining if a sites contains or has the potential for developing a karst feature.

In karst settings there are special considerations and potentially additional constraints needed prior to implementing most structural BMPs. A growing emphasis is being placed on the implementation of strategies that preserve the pre-development hydrology and maintain critical vegetated areas. This is based on the idea that, in a pre-development setting, the runoff was spread across the landscape rather than directed to a certain area, which often results when there is a high concentration of pervious surfaces. When stormwater is concentrated in one area, it can lead to a more rapid dissolution of the underlying rock ([American Rivers, n.d](http://www.eahcp.org/files/uploads/09-03-10Attachment4aUsing_Green_Infrastructure.pdf).).

The uncertainty related to the actual presence of karst, the presence of unstable materials that have the potential for development of karst, and the water movement through karst terrain dictates the level of additional field information to be collected before proceeding with BMP design and construction in Active Karst and Transitional Karst classifications. The following guidelines are based on adaptations from a handful of communities (e.g., Carroll County, MD (2004a and b); St. Johns River Water Management District, FL (2010); Jefferson County, WV (Laughland 2003); [Tennessee Permanent Stormwater Management and Design Guidance Manual – Appendix B](http://tnpermanentstormwater.org/manual.asp) (2014); and other documents ([Chesapeake Stormwater Network](http://chesapeakestormwater.net/training-library/design-adaptations/stormwater-in-karst-topography/) [Karst Working Group, 2009]; [West Virginia Stormwater Management & Design Guidance Manual](http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/Documents/Appendix_C_Stormwater_Mgmt_Design_Karst_WV-SW-11-2012.pdf) [asdfa]; [Infiltration and Karst: Design Considerations for Success](http://www.lccwc.com/pdf/Sem2_2011/Adams-KarstGeology_09_20_2011.pdf) [Adams, M. Powerpoint, N.D.]).

* **Conduct a thorough geotechnical investigation in areas with suspected or documented active karst**. Karst geology can change rapidly over very short distances so additional soil borings may be required in comparison to geotechnical investigations for shallow groundwater or bedrock.
* **Investigate non-infiltration BMPs on sites subject to the requirements of the CGP, where the infiltration BMP is “within 1,000 feet up-gradient or 100 feet down-gradient of active karst features unless allowed by a local unit of government with a current MS4 permit**”. For purpose of these guidelines, active karst features are defined as identified karst or identified unstable subsurface materials that have the potential for development of karst.
* **Preserve the maximum length of natural swales as possible** at the site to increase the infiltration and accommodate flows from extreme storms.
* **Minimize the area of impervious surfaces at the site**. This will reduce the volume and velocity of the stormwater runoff. **Consult with a geotechnical engineer prior to the design and construction of a BMP.** The effect of stormwater BMPs in a karst area is complex and hard to predict. Consulting with a professional can reduce the risks of geological hazards and groundwater contamination.
* **Capture the runoff in a series of small runoff reduction practices where sheet flow is present.** This technique will help keep the stormwater runoff from becoming channelized and will disperse the flow over a broad area. Practices such as swales, bioretention with underdrains, media filters, and vegetated filters should be considered first at a site. However, not all sites lend themselves to this type of management approach and could require use of the active karst region for proper management. Under these conditions, adequate precautions should be taken to assure that runoff water is adequately pretreated.
* **Design BMPs to be off-line such that volumes of runoff greater than the capacity of the BMP are bypassed around the BMP**. This approach will limit the volume through the BMP to a quantity that is manageable in the karst.
* **Install multiple small BMPs instead of a centralized BMP**. Centralized BMPs are defined as any practice that treats runoff from a contributing drainage area greater than 20,000 square feet, and/or has a surface ponding depth greater than 3 feet. Centralized practices have the greatest potential for karst- related failure, and will require costly geotechnical investigations and a more complex design.
* **Direct discharge from stormwater BMPs to surface waters and not to the nearest sinkhole**. Because karst areas can be quite large in Minnesota, discharges should be routed to a baseflow stream via a pipe or lined ditch or channel to redirect the flow away from the karst, provided the stream does not disappear into a karst feature.
* **Incorporate additional precautions where infiltration practices are used.** Impermeable liners and underdrains should be used in infiltration practices in active karst areas, effectively converting the infiltration BMP to a filtration BMP. These measures will be used to prevent the infiltrating water from discharging into the soils surrounding the karst feature. In addition, large scale practices (drainage area is greater than 20,000 square feet) are strongly discouraged.
* **Design ponds and wetlands with a properly engineered synthetic liner.** It is HIGHLY RECOMMENDED that a professional geotechnical engineer investigate and recommend the depth of unconsolidated material between the bottom of the pond and the surface of the bedrock. A minimum of 3 feet of unconsolidated soil material is the minimum separation , however an expert may recommend 10 feet or greater. Pond and wetland depths should be fairly uniform and limited to no more than 10 feet in depth.
* **Minimize site disturbance during BMP construction.** Seek the recommendations of a geotechnical engineer for management of heavy equipment, temporary storage of materials, changes to the soil profile - including cuts, fills, excavation and drainage alteration - on sites that have been found to contain a karst feature.
* **Report sinkholes as soon as possible after the first observation of sinkhole development.** The sinkhole(s) should then be repaired or the stormwater management facility abandoned, adapted, managed and/or observed for future changes, whichever of these is most appropriate.
* **Develop a contingency plan** for how to manage the stormwater should a BMP fail as a result of the development of a karst feature.

**Table 2.5** provides an overview of karst related design considerations for different structural BMP groups.

Table 2.5 Stormwater BMP Selection in Karst Regions

|  |  |  |
| --- | --- | --- |
| BMP | Suitability in Karst Regions | Notes |
| Impervious area disconnect | Preferred | * Strongly recommended for most residential lots less than 6,000 square feet. * Discharge point from the disconnect should extend at least 15 feet from any building foundation. |
| Bioretention with underdrain (biofiltration) | Preferred | * Requires 3 foot minimum separation distance between practice bottom and bedrock. If this is not possible, an underdrain should be used to convey the water away. * It’s recommended that the drainage area to an individual bioretention BMP be kept less than 20,000 square feet. * Larger designs that rely on exfiltration of treated runoff into the soils below are not recommended. |
| Rain tank/cistern | Preferred | * Above ground tanks are preferred to below ground. * Overflow of tank should extend at least 15 feet from building foundation. |
| Rooftop disconnect | Preferred | * 15 feet foundation set back. * Runoff should be spread diffusely across landscape. |
| Green roofs | Preferred | * Runoff should be spread diffusely across landscape. |
| Dry Swale or  Grassed Channel | Preferred | * Line with underdrains. * Incorporate compost amendments into the bottom of the channel to improve runoff reduction for vegetative uptake, and transpiration. * Do not incorporate check dams unless the swale or channel incorporates an underdrain. Otherwise small areas of infiltration would develop in the zones upgradient of the check dam where the water is captured without adequate outlet. |
| Media filter | Preferred | * Recommended practice in areas of shallow bedrock and soil. |
| Vegetative filter | Preferred | * Recommended practice in areas of shallow bedrock and soil. |
|  |  |  |
| Soil compost amendment | Adequate |  |
| Small scale infiltration  Micro-bioretention | Adequate | * Create multiple small sized infiltration BMPs to infiltrate impervious areas of 250 to 2,500 square feet. * Not recommended for sites identified as a stormwater hotspot. |
|  |  |  |
| Permeable Pavers | Adequate |  |
| Infiltration trench or basin |  | * Surface area to depth ratios of practices may need to be larger than typical basin designs to minimize depth of the BMP. * Confirm suitability with supporting geotechnical investigations and calculations. * Not recommended for sites identified as a stormwater hotspot. * Incorporate pre-treatment to limit risk of groundwater contamination in the event of future failure of the BMP associated with development of a karst feature. Local review authority should be consulted for approval. |
| Constructed wetlands | Adequate | * Requires larger surface area to drainage area ratios to limit the depth of the wetland. * Bedrock should act like a liner and help to maintain a permanent pool, unless fracture zone is present. * Use liner and liner cells. |
| Dry extended detention (ED) ponds and wet ponds | Adequate | * Requires larger surface area to drainage area ratios to limit the depth of the basin or pond. If analysis shows that the soils can support the weight of a pond then a liner should be used.to prevent infiltration |
| Wet swale | Discouraged | * Not feasible. |
| Large scale infiltration | Discouraged | * Use small scale infiltration practices instead. |
| Sources Karst Working Group, 2009; Minnesota Stormwater Wiki; Tennessee Permanent Stormwater Management and Design Guidance. | | |

2.6.5 Monitoring of Groundwater and Stormwater Runoff in Karst Regions

A water quality monitoring system installed, operated, and maintained by the owner/operator is RECOMMENDED, particularly where drinking water supplies are derived from ground water or associated with known sources of contamination. The location of monitoring wells or BMP performance monitoring will depend upon the nature of the BMP and surrounding karst characteristics. This could mean the installation of a monitoring system designed to reflect variable water behavior typical of karst water flow in addition to the monitoring of the performance of the BMP. Monitoring of groundwater and stormwater runoff behavior requires a thorough understanding of the local geology, as the hydrology of karst terrains is vastly different from that of non-karst terrains (EPA, 1989). Below is a list of resources that provide additional information on runoff and/or groundwater monitoring in karst areas:

* [**Ground-Water Monitoring in Karst Terrains: Recommended Protocols & Implicit Assumptions**](http://www.epa.gov/OUST/cat/gwkarst.pdf)(EPA, 1989). This report provides information on the monitoring procedures and common monitoring pitfalls in karst areas. It describes where to monitor for pollutants, where to monitor for background water quality, when to monitor the groundwater, and how to do all this reliably and economically.
* **Highway Stormwater Runoff in Karst Areas – Preliminary Results of Baseline Monitoring and Design of a Treatment System for a Sinkhole in Knoxville Texas** (Stephenson et al., 1999). The authors of this report discuss the use of quantitative dye tracing and hydrograph analyses to monitor stormwater runoff and resulting groundwater flow from runoff from a highway system.
* [**Evaluating the Effectiveness of Regulatory Stormwater Monitoring Protocols on Groundwater Quality in Urbanized Karst Regions**](http://digitalcommons.wku.edu/cgi/viewcontent.cgi?article=2414&context=theses) (Nedvidek, 2014). This report looks at monitoring techniques and frequencies. It also discusses how to make these monitoring programs cost effective, while still providing a sufficient amount of information.

2.6.6 How to Remediate After a Sinkhole Appears

There are several approaches to sinkhole remediation if such an approach is desirable. Sinkhole sealing involves investigation, stabilization, filling, and final grading. In the investigation phase, the areal extent and depth of the sinkhole(s) should be determined. The investigation may consist of excavation to bedrock, soil borings, and/or geophysical studies. Sealing small-sized sinkholes is normally achieved by digging out the sinkhole to bedrock, plugging the hole with concrete, installing several impermeable soil layers interspersed with plastic or geotextile, and crowning with an impermeable layer and topsoil. For moderate sinkholes, an engineered subsurface structure is usually required.

It is often not feasible to seal large sinkholes so other remediation options must be pursued. These could include construction of a low-head berm around the sinkhole, clean-out of the sinkhole to make sure all potentially contaminating materials are removed, landscaping and conversion of land use in the sinkhole to open space or recreation, provided it can be done in a manner that provides adequate safety. In any of these cases, pre-treatment of any stormwater entering the sinkhole is imperative. Final grading of sinkholes in open space settings should include the placement of low permeability topsoil or clay and a vegetative cover, with a positive grade maintained away from the sinkhole location to avoid ponding or infiltration, if feasible.

Additional information on sinkhole remediation can be found at:

* [**Problems Associated with the Use of Compaction Grout for Sinkhole Remediation in West-Central Florida**](http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1109&context=sinkhole_2013) (Zisman, 2013). This paper presents information regarding the improper application of compaction grouting in sinkholes.
* [**The Characterization and Remediation of Sinkholes**](http://semanticommunity.info/@api/deki/files/838/=BobDenton09172008.pdf) (Denton, N.D. – PowerPoint Presentation). The PowerPoint presentation presents an overview of karst geology and some common remediation techniques.
* Development Mechanism and Remediation of Multiple Spontaneous Sinkholes: A Case Study (Jammal et al., 2010). This journal article provides information on how to remediate when multiple sinkholes are present.
* [**Sinkholes and Seepage: Embankment Repair at Hat Creek 1**](http://www.hydroworld.com/articles/hr/print/volume-32/issue-7/cover-story/sinkholes-and-seepage-embankment-repair-at-hat-creek-1.html) (Bowers et al., 2013). This article discusses geotechnical investigation and engineering solution regarding a sinkhole that was discovered near a Pacific Gas and Electric Company hydroelectric project.
* [**Tennessee Permanent Stormwater Management and Design Guidance Manual – Appendix B** (2014)](http://tnpermanentstormwater.org/manual.asp). This section of Appendix B provides a brief overview of sinkhole notification, investigation, stabilization, and final grading.
  1. Contaminated Soils and Groundwater

2.7.1 What are Contaminated Sites?

The CGP PROHIBITS the use of infiltration BMPs in areas where the infiltrating stormwater will mobilize the contaminants. However, stormwater infiltration BMPs may be feasible at sites with known contaminated soils or groundwater under certain conditions. Contaminated sites include, but are not limited to, the following:

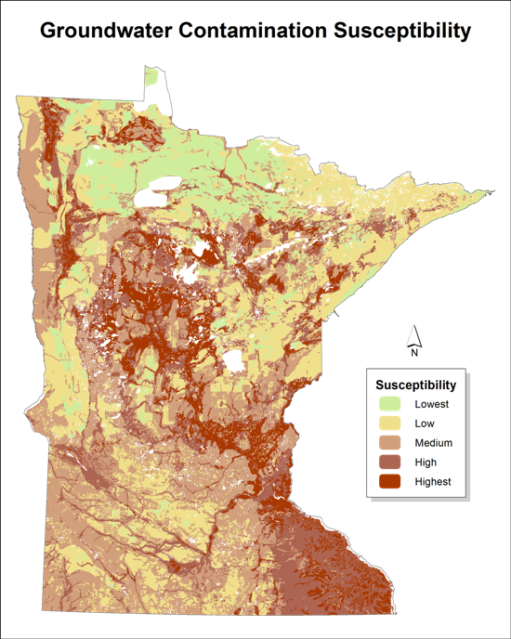
* **Brownfields.** A brownfield is a property where redevelopment or reuse may be complicated by the presence (or likely presence) of contamination. Brownfields may include vacant parcels, depending on their prior use. A wide variety of contaminants may be found at a Brownfield site depending on the previous use. Common types of brownfields, along with typical contaminants, are as follows ([U.S.EPA](http://www.epa.gov/brownfields/tools/ec_information_guide.pdf), 2010):
* **Gasoline service stations and auto body repair shops:** Typically contaminated with petroleum hydrocarbons found in underground storage tanks (USTs), metals associated with motor and hydraulic oils, and cleaning solvents.
* **Industrial properties:** Typically contaminated with asbestos, heavy metals, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and polychlorinated biphenyls (PCBs).
* **Commercial properties (e.g., dry cleaning operations):** Typically contaminated with asbestos, VOCs, polycyclic aromatic hydrocarbons (PAHs), and PCBs.
* **Landfills and dumps:** Typically contaminated with oils, paints, solvents, corrosive cleaners, batteries, VOCs, PAHs, and PCBs.
* **Superfund Sites.** A Superfund site is a site that is regulated under the Superfund program, established under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) and implemented by the U.S. EPA. These sites are abandoned, uncontrolled hazardous waste sites ([U.S. EPA, 2011](http://www.epa.gov/region2/waste/dupont_pompton/pdf/RCRAvsSuperfund_factsheet.pdf)). A list of sites can be found on the [National Priorities List](http://www.epa.gov/superfund/sites/npl/index.htm). Information can also be found on the MPCA’s webpage under the [Superfund Program Site Search](http://www.pca.state.mn.us/index.php/waste/waste-and-cleanup/cleanup/superfund/superfund-site-search.html). As with Brownfields, a wide variety of pollutants can be present. Some of the common pollutants found at Superfund sites include, but are not limited to, organics (e.g. creosote and phenols), industrial solvents (e.g. trichloroethylene [TCE], tetrachloroethene [PCE], and trichloroethane), waste inks, caustics and acids, paints and paint thinners, VOCs, and asbestos.
* **RCRA sites.** RCRA, or Resource Conservation and Recovery Act, sites are hazardous wastes sites but, unlike Superfund sites, are currently in use (U.S. EPA, 2011). Many of the pollutants found at Superfund sites will also be found in RCRA sites. A list of RCRA sites can be found on the MPCA’s webpage under [RCRA Cleanup Site Search](http://www.pca.state.mn.us/index.php/waste/waste-and-cleanup/cleanup/superfund/rcra-cleanup-site-search.html).
* **Underground or Aboveground Storage Tank Sites.** Storage tank sites that are of concern are those sites which store petroleum or hazardous substances. Common pollutants stored in tanks are petroleum products (e.g., gasoline and diesel), fuel oil, and other liquid hazardous chemicals. A list of leaks/tank sites can be found on the MPCA’s webpage under [Leaks/Tanks Search](http://cf.pca.state.mn.us/programs/tank_leak/index.cfm?site=leak).

The MPCA provides a search engine called [What’s in My Neighborhood](http://www.pca.state.mn.us/index.php/data/wimn-whats-in-my-neighborhood/whats-in-my-neighborhood.html)? This online application allows a user to search for known contaminated sites in areas near or on a site proposed for a stormwater BMP.

**2.7.2 What Rules Regulate Stormwater Management at a Contaminated Site?**

Groundwater rules are contained in [Minnesota Rule 7060](https://www.revisor.mn.gov/rules/?id=7060). These [rules](http://www.pca.state.mn.us/index.php/view-document.html?gid=18901) were adopted to preserve and protect the underground waters of the state by preventing any new, and abating existing, underground water pollution. These rules form the basis for groundwater protection efforts in several MPCA programs, and include: a) defined uses of underground waters; b) a non-degradation policy for the MPCA to follow to ensure underground waters of the state are maintained at their natural quality; and c) standards (e.g., prohibitions) to protect the underground waters of the state.

Sensitive areas are of particular concern for contaminated sites. “Sensitive Areas” are defined in [Minnesota Statues 103H.005](https://www.revisor.mn.gov/statutes/?id=103H.005) Subd. 13 as geographic areas defined by “natural features where there is a significant risk of groundwater degradation from activities conducted at or near the land surface.” **Figure 2.8** shows the relative susceptibility of areas in MN as delineated by the MPCA. Additional information about groundwater pollution sensitivity, including definitions of the five relative classes of geologic sensitivity (based on time of travel) provided by the MN DNR is available [here](http://www.dnr.state.mn.us/waters/groundwater_section/mapping/sensitivity.html). The index is based on the Groundwater Contamination Susceptibility model by the Minnesota Pollution Control Agency (Porcher, 1989).



**Figure 2.8 Groundwater contamination susceptibility in Minnesota** (Source: ©2012 Minnesota DNR, with permission).

The [MPCA’s Brownfield Program Response Action Plans](http://www.pca.state.mn.us/index.php/view-document.html?gid=19473), 2013 (RAP) provides guidance for stormwater management at sites under the Petroleum Brownfields (PB) Program and the Voluntary Investigation and Cleanup (VIC) Program. While the Brownfield program does not approve stormwater plans, the MPCA does require that applicable stormwater design information be included in the RAP. This program offers the following options (MPCA, 2013):

* Locate the stormwater management to an area of the site that is not anticipated to mobilize contaminants.
* Model the subsurface hydrologic setting to demonstrate that existing or residual contamination will not be adversely affected by the stormwater design feature.
* Remove soil contamination so as to accommodate infiltration practices.
* Consider a non-infiltration stormwater management system.

2.7.3 How to Determine if a Site Might be Contaminated

Sources for information on determining site contamination are available from both the American Society for Testing and Materials (ASTM) and USEPA. These agencies provide information on the basics of performing Phase I Environmental Site Assessments (ESA). The purpose of a Phase I ESA is to identify recognized environmental conditions (RECs), as defined by ASTM, which may exist on a site and assess whether any environmental impacts were likely present based on current and/or past on-site activities.  An ESA is conducted in accordance with the current ASTM Practice E 1527-13, Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process and 40 CFR Part 312, Standards and Practices for All Appropriate Inquiries.  At a minimum, a Phase I ESA should include:

* A reconnaissance of the site to evaluate current property use and conditions, and observations of current general land use and conditions in the area immediately surrounding the site.
* A Review of property history utilizing the following information sources as available:
* Street directories
* Aerial photographs
* Topographic maps
* Sanborn, Kroll, Metzker and/or other historical maps
* Historical tax assessor records
* Interview of persons knowledgeable of the property and area to obtain current and historical information (i.e., current property owner, tenants etc.).
* Examination of state and federal records to identify if the property and adjacent or nearby properties or businesses are documented hazardous waste generators and/or are known or suspected of having contamination.
* Review of information provided by the owner, such as prior environmental reports, information on environmental cleanup liens, activity and land use limitations, purchase price relative to fair market value of the property, commonly known information regarding the property, as well as the chain-of-title, site drawings, and other pertinent information.
* Preparation of a report that presents findings, opinions, and conclusions regarding contamination or the potential for contamination on or near the site.

Indications of contamination could include discolored soil or standing water, unusual odors, dead or weak vegetation, and/or mismanaged drums or chemical containers.

USEPA’s [EnviroMapper](http://www.epa.gov/emefdata/em4ef.home) and the MPCA’s [What’s in My Neighborhood](http://www.pca.state.mn.us/index.php/data/wimn-whats-in-my-neighborhood/whats-in-my-neighborhood.html) are online tools that can be used to research environmental information for specific sites and locations.

If sources or potential sources of contamination are determined through a Phase I ESA, a Phase II ESA should be conducted, which may include soil and groundwater sampling and regulatory concentration analysis. If unacceptable levels of pollutants are determined to be present, a supplemental site assessment may be performed per local and federal regulations, to assess the extent of the extent of soil and/or water contamination. Several qualified environmental assessment firms typically perform ESA services in Minnesota.

The U.S. EPA publication titled [Implementing Stormwater Infiltration Practices at Vacant Parcels and Brownfield Sites](http://www.epa.state.il.us/water/watershed/publications/implementing-stormwater-infiltration-practices.pdf) (U.S. EPA, 2013) provides a general overview of the investigative process.

2.7.4 What are General Stormwater Management Guidelines for Contaminated Sites?

2.7.4.1 General Guidelines

Managing stormwater at sites with contaminated soils or groundwater is challenging because the infiltrated runoff has the potential to transport contaminants to the surface or groundwater. Stormwater at contaminated sites can be managed by capture and treatment, as infiltration, or through avoiding contact between runoff and contaminated soils and groundwater (Hollander et al., 2010).

Another complication with contaminated sites, beyond the contamination itself, is the fact that remediation for redevelopment usually involves the placement of an impermeable cap over the contaminated area. This creates a challenge for the designers as it limits the space available for stormwater management and increases the amount of runoff that must be managed.

Direct infiltration into the subsurface is not recommended at most contaminated sites as it could mobilize the pollution into the groundwater and will move the plume off the site. Instead, practices should be used that “can retrain, treat and then release the stormwater without allowing the water to come in contact with the contaminated soil” (EPA, 2008).

When designing a stormwater management system at a contaminated site, it is important to acquire a thorough understanding of both the types and locations of the contamination present, as well as the subsurface conditions at the site (SEMCOG, 2008). Of particular concern are those contaminates that are mobile and/or biodegradable as those will have the greatest potential to impact the groundwater (EPA, 2013). Other sources of contamination could still be a concern, however, and need to be considered. For example, metals are often filtered out near the surface because they bind to the suspended solids. In some situations, however, the pH of the stormwater runoff or the presence of other contaminants can cause the metals to remobilize and filter into the subsurface where they would then have the potential to reach the groundwater. Careful consideration must be used when designing any stormwater BMP at a contaminated site.

The EPA provides the following guidelines for incorporating green infrastructure into a Brownfield site in their document titled [Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas](http://www.epa.gov/brownfields/tools/swdp0408.pdf) (EPA, 2008).

* **Guideline #1:** Differentiate between groups of contaminants as a way to better minimize risks.
* **Guideline #2:** Keep non-contaminated stormwater separate from contaminated soils and water to prevent leaching and spreading of contaminants.
* **Guideline #3:** Prevent soil erosion using vegetation, such as existing trees, and structural practices like swales or sediment basins.
* **Guideline #4:** Include measures that minimize runoff on all new development within and adjacent to a brownfield. These measures include green roofs, green walls, large trees, and rainwater cisterns.

Additional guidelines can be found in the Low Impact Development Manual for Michigan (SEMCOG, 2008). The guidelines presented in the document have been reviewed and adapted by the Michigan Department of environmental quality and consist of:

* **Avoid infiltration practices in contaminated areas.** Practices that could be considered are detention, retention, and biofiltration, as long as the runoff does not achieve complete infiltration in the underlying soils. The runoff could be treated and stored and, in some cases, be reused for other things. In many cases a liner and underdrain will be required to ensure that the runoff does not come in contact with the contaminated soil.
* **Retain/re-vegetate trees and vegetation**. Vegetation will capture and evapotranspire the stormwater runoff as well as intercept some of the rainfall before it hits the ground.
* **Implement practices that encourage evapotranspiration and capture/reuse**. This relates the above bullet about retaining/re-vegetating the site but also includes practices such as green roofs and cisterns.

**2.7.4.2 Is it possible to infiltrate near contaminated soils[[1]](#footnote-1)?**

While infiltration at contaminated sites is not the most desired stormwater management option, it may be highly desirable in some locations. If infiltration BMPs are being considered, additional testing and considerations will be required to ensure that there are no adverse effects to the groundwater or surrounding area. Of particular concern is the potential of the pollutant to leach into the groundwater. To determine the likelihood of this, the U.S. EPA has developed the Synthetic Precipitation Leaching Procedure, or SPLP (USEPA Method 1312). First, soil is collected from the contaminated area. Next, the soil is mixed with laboratory grade water and placed into a rotary agitator for 18 hours. After the required time is up, water from the mixture is tested to determine how much of the contamination leached out. The results are be compared to all applicable standards to see if they exceed any of the limits. If the limits are exceeded, infiltration should not be used. **Caution should be used when implementing this testing methods as stormwater runoff may react differently with the pollutants than laboratory grade water due differences in water quality parameters.**

Another consideration regarding infiltration at a contaminated site is whether or not the groundwater present is contaminated since infiltration practices have the ability to accelerate the movement of groundwater. This relates to sites upstream and downstream of contaminated areas as well. SEMCOG (2008) presents an exception to this restriction. It states that, under some circumstances, infiltration may be preferable at sites with groundwater contamination plumes, such as site where there is little risk that the contamination will migrate off-site and where natural attenuation is being used as the remediation strategy. In this situation, the “clean” rainwater could help accelerate the process of natural attenuation. Designing and implementing this project would require working closely with experts and regulators to ensure that the contamination is actually being treated and isn’t migrating off site. Monitoring would most likely be required.

It may also be possible to move the infiltration practice to an area on the site that is not contaminated, as long as infiltrating in that location does adversely impact areas the surrounding contaminated areas. In some situations, the contaminated soil could be removed and replaced with clean soil, allowing for infiltration.

Before designing and implementing an infiltration BMP at a contaminated site, it should be determined that the infiltration practice will not affect any of the required remediation practices. Infiltration near vertical barriers, for example, could cause the barriers to fail by causing an increase in hydraulic pressure at the barrier resulting in leaks and decreased effectiveness of the barrier.

Finally, the impact of the contaminated site on nearby lands need to be studied when considering the use of an infiltration BMP. When situated near an area that is “relatively more sensitive in terms of potential health risks or ecological risks” additional protection may need to be considered. The factor of safety related to these sites is much greater.

**2.7.4.3 Additional Resources for Stormwater Infiltration at Contaminated Sites**

Other resources that may provide more guidance on stormwater management at contaminated sites are provided below:

* [**Case Studies for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas**](http://www.epa.gov/brownfields/tools/swcs0408.pdf)(EPA, 2008). This document is a companion to the EPA document discussed above (Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas). Three case studies are presented that demonstrate the incorporation of green infrastructure into Brownfield sites.
* [**Rhode Island: Section 3.2.8 RISDM Subsurface Contamination Guidance**](http://www.dem.ri.gov/programs/benviron/water/permits/swcoord/pdf/wastswgu.pdf)(RISDISM, 2014). This document from the Rhode Island Department of Environmental Management provides guidance in locating stormwater systems on a contaminated site. The authors suggest dividing the site into three zones; red, yellow, and green, which are based on the allowable hydraulic loads. The red zones are areas with active remediation or known contamination on or near the zone. In these areas no hydraulic loading is allowed into the subsurface. A hard cap is required and any BMPs must be lined. In the yellow zone a soft cap or direct precipitation is allowed. The BMPs that are acceptable are those with no concentrated flow. Green zones allow for unrestricted hydraulic loading. The document goes into some detail of hoe to determine the extent of each zone.
* [**Best Management Practices for Controlling Runoff during Remediation at Contaminated Sites**](http://www.alachuacounty.us/Depts/EPD/Documents/WaterResources/Remediation%20BMP.pdf)(Alachua County Environmental Protection Department, N.D.). This factsheet from the Alachua County Environmental Protection Department provides information to guide the user in the determination of applicable BMPs at petroleum or other contaminated sites.
* [**Sustainable Stormwater Management on Redeveloped Brownfield Sites in New York City**](http://swimmablenyc.info/wp-content/uploads/2012/05/Sara-Margolis-Final-Thesis-Presentation.pdf)(Margolis, N.D.; PowerPoint). This thesis final presentation provides information regarding stormwater management on redeveloped brownfield sites in New York City. The author suggest maximizing the amount of vegetation as well as utilizing an underdrain system in the BMP.
* [**Sustainable Water Management on Brownfield Sites**](http://louisville.edu/cepm/projects/sustainable-community-capacity-building/green-infrastructure-on-brownfields)(Fenwick, 2012). This report provides guidance on water management solutions at Brownfield sites. In addition to the other information presented in the report, the authors suggest two low impact development (LID) approaches that have been used successfully on brownfield sites. First is to use impermeable liners or gravel filter blankets in conjunction with the stormwater management practices. Second is to install a rainwater harvesting system.

2.7.4.4 Minnesota Case Studies

There have been situations in Minnesota where stormwater has been considered at contaminated sites, as described below.

* Parcel 5 of the 3m East 7th Street Site, VP24800/PB3785.  Infiltration tank. With the St.Paul Port Authority and won awards for design.
* Open Arms Site, VP23670 in S. Mpls.  An infiltration system installed with oversight of SW folks.
* Lunds on Hennepin, VP19242 in Mpls.
* CVS Pharmacy Store #06507, VP28540, in St. Cloud.
* Site 7921 involved an excavation and then a MNDOT storm water retention pond build where the leak site was.
* CCLRT through the UofM where a large infiltration gallery was installed on a portion of the U property, and further east where a gallery was not installed. Petroleum Brownfields Program (PBP) file numbers 3794-3796.
  1. Potential Stormwater Hotspots

2.8.1 What are Potential Stormwater Hotspots?

Potential Stormwater Hotspots (PSHs) are activities, or practices within commercial, industrial, institutional, municipal, or transportation-related land uses that **have the potential to** produce relatively high levels of stormwater pollutants. PSHs primarily include locations where there is a potential risk for spills, leaks, or illicit discharges.

**Designation as a PSH does not imply that a site is a hotspot, but rather that the land use and associated on-site activities have the potential to generate higher pollutant runoff loads compared to other land uses.** Designation as a PSH serves as a reminder to owners, designers and reviewers that more careful consideration of the site is warranted. Ultimately, a site that is formally designated as a hotspot will likely dictate that certain practices and/or design criteria are prohibited or discouraged.

Common concentrations of select pollutants in stormwater runoff at the various PSH categories are provided in **Table 2.6.**

Table 2.6 Common Concentrations of Pollutants of Concern Found in Stormwater Runoff at Various Land Use Areas

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Land Use | | N02+NO­ (mg/L) | TN (mg/L) | TP (mg/L) | Chloride2 (mg/L) | Cu (ug/L) | Zn (ug/L) | TPH | Fecal2 Coliform | **E. Coli** | **F. S.** |  |
| Commercial1 | | | | | | | | | |
| Number of sites | | 50 | 13 | 56 | -- | 60 | 62 | 2 | 4 |
| Number of observations | | 786 | 77 | 948 | -- | 785 | 867 | 21 | 19 |
| % of samples above the detection limit | | 98.9% | 97.4% | 94.5% | -- | 85.0% | 99.2% | 76.2% | 73.7% |
| Minimum | | <0.1 | <1.5 | <0.01 | -- | <0.2 | <0.3 | <0.6 | <200 |
| Maximum | | 8.2 | 18.1 | 4.27 | -- | 569.1 | 3,050.5 | 13 | 28,000 |
| Median | | 0.6 | 1.75 | 0.2 | -- | 17 | 110 | 16 | 450 |
| Industrial1 | |  |  |  |  |  |  |  |  |
| Number of sites | 58 | 51 | 13 | 1 | 65 | 67 | 4 | 6 |
| Number of observations | 619 | 536 | 85 | 10 | 569 | 627 | 26 | 32 |
| % of samples above the detection limit | 99.5% | 97.0%% | 95.3% | 50.0% | 85.1% | 98.9% | 88.5% | 90.6% |
| Minimum | <1 | <0.02 | <1.5 | <2 | <0.2 | <0.5 | <0.5 | <1 |
| Maximum | 2,490 | 8.4 | 15.2 | 7.8 | 1,360 | 8,100 | 12 | 3,6000,000 |
| Median | 75 | 0.68 | 1.7 | 6 | 19 | 155 | 3 | 3,950 |
| Intuitional1 |  |  |  |  |  |  |  |  |
| Number of sites | | 3 | 1 | 3 | -- | 3 | 3 | -- | 1 |
| Number of observations | | 53 | 7 | 53 | -- | 53 | 53 | -- | 3 |
| % of samples above the detection limit | | 98.1% | 100% | 98.1% | -- | 79.2% | 100% | -- | 100% |
| Minimum | | <MDL3 | 0.83 | <0.03 | -- | <5 | 47 | -- | 1,600 |
| Maximum | | 2.04 | 2.38 | 0.98 | -- | 90.8 | 1,300 | -- | 4,300 |
| Median | | 0.6 | 1.4 | 0.19 | -- | 22.1 | 170 | -- | 3,400 |
| Municipal4 | |  |  |  |  |  |  |  |  |
| Number of sites | | -- | -- | -- | -- | -- | -- | -- | -- |
| Number of observations | | -- | -- | -- | -- | 6 | 7 | -- | -- |
| % of samples above the detection limit | | -- | -- | -- | -- | -- | -- | -- | -- |
| Minimum | | -- | -- | -- | -- | 1.0 | 3.0 | -- | -- |
| Maximum | | -- | -- | -- | -- | 1,520 | 100 | -- | -- |
| Median1 | | -- | -- | -- | -- | 250 | 22 | -- | -- |
| Transport Related5 | |  |  |  |  |  |  |  |  |
| Number of sites | |  |  |  |  | -- | -- |  | -- |
| Number of observations | | -- | -- | -- | -- | 3-16 | 3-16 | -- | -- |
| % of samples above the detection limit | | -- | -- | -- | -- | -- | -- | -- | -- |
| Minimum | | -- | -- | -- | -- | 1.0 | 2 | -- | -- |
| Maximum | | -- | -- | -- | -- | 61 | 560 | -- | -- |
| Median1 | | -- | -- | -- | -- | 6.7 | 23.5 | -- | -- |

1Data is from the National Stormwater Database,

2Data is for northern climates only

3No value was given for the detection limit

4Data is from Pitt et al., 1995. Values are based on concentrations reported for storage areas

5Data is from Pitt et al., 1995. Values are based on concentrations reported for parking areas, street runoff, loading docks, and vehicle service areas

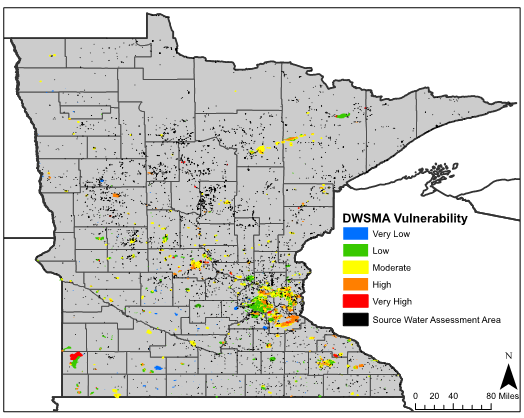
Hotspots can be classified as Regulated, subject to state or federal permits, or Unregulated. In Minnesota Regulated hotspots are subject to the [NPDES Multi-Sector General Permit for Industrial Activity](http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/industrial-stormwater/index.html), and/or local ordinances. Because Stormwater Hotspots are found in a variety of land uses, there is no common pollutant for any type of hotspot. Instead the pollutants tend to be a unique mixture of pollutants (CWP, 2005). The potential for hotspots is related to the activities on the site more than the land use or category of operation. Table 2-7 generalizes the most common pollutants generated at stormwater hotspots based on the most common operations at a site.

Table 2-7 Pollutants of Concern from Operations (adapted from CWP, 2005)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pollutant of Concern | Vehicle Operations | Waste Management | Site Maintenance Practices | Outdoor Materials | Landscaping |
| Nutrients |  |  | ✓ | ✓ | ✓ |
| Pesticides |  |  |  | ✓ | ✓ |
| Solvents |  |  | ✓ | ✓ |  |
| Fuels |  |  |  | ✓ |  |
| Oil and grease | ✓ |  |  | ✓ |  |
| Toxic chemicals |  | ✓ |  | ✓ |  |
| Sediment |  | ✓ | ✓ | ✓ | ✓ |
| Road salt |  |  | ✓ | ✓ |  |
| Bacteria |  | ✓ |  |  | ✓ |
| Trace metals | ✓ |  |  | ✓ |  |
| Hydrocarbons | ✓ |  |  | ✓ |  |

Preventing or minimizing the likelihood of contaminated runoff from leaving a site is the core objective of stormwater management at these hotspots. Introduction of contaminated runoff to the ground water is probably the greatest concern in developing effective stormwater management plans at PSHs. This is because

* ground water contamination is hard to detect immediately and therefore can persist over long periods of time prior to any mitigation;
* there is an immediate public health threat associated with ground water contamination in areas where ground water is the primary drinking water source, and
* mitigation, when needed, is often difficult and is usually very expensive.



**Figure 2.9 January 2004 location of Source Water Protection Areas in Minnesota.** (Source: CDM Smith, using information from the MN Department of Health, <http://www.health.state.mn.us/divs/eh/water/swp/maps/index.htm>)

Figure 2.9 shows highlights vulnerability designations for Drinking Water Source Management Areas in Minnesota, ranges from very low to very high vulnerability, and designation of Source Water Assessment areas as vulnerable to not vulnerable Note: This shows only the public systems covered under the Minnesota Department of Health program. There are thousands of additional private and domestic wells that could be impacted by PSHs and not subject to any special protections against stormwater runoff.

2.8.2 How to Determine if a PSH is a Hotspot

As stated previously, the designation of PSH does not mean a site is a hotspot, only that the land use and associated on-site activities have the potential to generate higher pollution runoff loads as compared to their land uses. When designing a stormwater management system at these sites, it is important to determine if the PSH is an actual hotspot. If it is a hotspot, additional stormwater management controls may be needed. The process of determining whether or not the PSH is a hotspot is as follows:

**Step 1: Consider where the activities take place.** If all activities using hazardous materials occur inside a building, and no materials can be tracked outside, then the site is not a hotspot. The various activities involving hazardous materials should be monitored at regularly scheduled intervals to ensure that nothing changes that would cause the hazardous materials to come in contact with the runoff.

**Step 2: Review the SWPPP, if present.** Sites subject to NPDES requirements through the Industrial Multi-Sector Permit or the MS4 Municipal General Permit may have created SWPPPs that guide the operations and housekeeping at sites where the potential for increased concentrations of certain pollutants in the runoff.

**Step 3: Conduct a site inspection.** The [Center for Watershed Protection](http://www.cwp.org/online-watershed-library/doc_download/459-urban-subwatershed-and-site-reconnaissance-field-forms) (CWP) has developed inspection forms that can be used to record physical operations and observations at a site to assess whether the site should be designated as a hotspot. For sites with a SWPPP, the inspection should include whether the site is operated in compliance with the requirements in the SWPPP. The CWP form includes an overall assessment of whether to designate the site as a hotspot.

**Step 4: Sample collection and analysis.** Further analysis may be required to determine if the PSH is a hotspot. Samples of the stormwater runoff at the site should be collected and analyzed for the pollutants of concern. Samples need to be collected form the runoff that is in contact with the hazardous waste to ensure that there is accurate site characterization. Recommendations for design adjustments are included in the following section.

2.8.3 What are General Stormwater Management Guidelines at PSHs and Hotspots?

Even if a PSH is determined to not be a hotspot, some additional considerations are needed for stormwater management. Runoff management at PSHs and hotspots should be linked to the pollutant(s) of greatest concern. Understanding the pollutants potentially generated by a site operation provides designers with important information on proper selection, siting, design, and maintenance of nonstructural (e.g., source control or pollution prevention) and structural practices that will be most effective at the site. Active inspection and monitoring of the site activities is required to ensure that a PSH does not become a hotspot.

Non-structural approaches such as sweeping, indoor storage, employee training, and frequent trash collection should be employed as much as possible. Not only will it prevent stormwater generation, it is also the most cost effective approach. To do this effectively, it is necessary to have a thorough understanding of a site and the respective areas of the site where specific operations will occur. Hogland, et al. (2003) suggest the following principles for design at PSHs and hotspots.

* Develop detailed mapping of the different areas of the site along with associated planned activities and the preliminary drainage design. Identify PSHs on the site (i.e. areas where pollutants may potentially be released) and attempt to eliminate or minimize the likelihood there will be a release. Within PSHs,
* Prevent or confine drips and spills.
* Enclose or cover pollutant generating activity areas and regularly provide cleanup of these areas.
* Provide spill prevention and clean-up equipment at strategic locations on site.
* Provide pre-treatment and spill containment measures such as catch basins and inserts, oil-water separators, etc.
* Strategically locate slopes and separation berms to prevent co-mingling of the runoff that does and does not come in contact with the pollutant of concern.
* Retain and reuse stormwater for irrigation, wash down water, or other onsite uses.
* Maintain equipment to minimize leaks.
* Train and educate employees, management and customers.

Meeting the design intent of the non-structural practices above typically involves simple and low-cost measures to address routine operations at a site. For example, the non-structural design components for a vehicle maintenance operation might involve the use of drip pans under vehicles, tarps covering disabled vehicles, dry cleanup methods for spills, proper disposal of used fluids, and covering and secondary containment for any outdoor storage areas.

Each of these practices also requires employee training and strong management commitment. In most cases, these practices save time and money, reduce liability and do not greatly interfere with normal operations. A more complete summary of 15 basic pollution prevention practices applied at PSH operations is provided in the table [here](http://stormwater.pca.state.mn.us/index.php/Pollution_prevention_practices_for_PSH_operations).

After considering the non-structural elements to incorporate into a site, designers need to assess what structural practices will provide the greatest pollutant loading reductions for targeted pollutants, if the pollutant is present in the runoff, given site constraints. Details on BMP design and performance can be found within web pages for individual BMPs.

Caution, the literature contains a large amount of information concerning BMP removal capability for a range of common pollutants. When using this information, be aware of the assumptions and limitations of the data. Some of this data has been compiled for this Manual. See data on BMP removal for the following pollutants but note that this is removal from the runoff that reaches the BMP only. It does not include any of the water that bypasses the system. In the case of infiltration BMPs, the values shown are for the pollution reduction from the runoff and does not take into account the fate and potential transport of the pollution within the system. Targeted pollutants are phosphorous, TSS, TN, hydrocarbons, bacteria, and metals.

The receiving water designation or watershed classification often drives the criteria and associated practices that are acceptable for use. However, at PSHs there is a set of general guidelines to consider when designing structural stormwater management systems. The following should be carefully considered by designers when specifying and siting practices at PSHs, specifically when it is determined that the site is an actual hotspot.

* **Pre-treatment.** This includes properly sizing sediment trapping features such as forebays and sedimentation chambers; incorporating appropriate proprietary and nonproprietary practices for spill control purposes and treatment redundancy; oversizing pre-treatment features for infiltration facilities such as swales, filter strips, and level spreaders; and ensuring full site stabilization before bringing practices online. If infiltration is to be utilized, appropriate site and conveyance designs are needed and the pre-treatment BMP size should be increased, or design redundancies are needed.
* **If pollutant generating activities exist on a site, runoff from these areas should be treated separately from other runoff at the site.** BMPs such as bioretention, ponds and wetlands that receive runoff from pollutant generating activities should be designed with the necessary features to minimize the chance of groundwater contamination. This includes using impermeable liners. The use of [ponds](http://stormwater.pca.state.mn.us/index.php/Stormwater_ponds) and [wetlands](http://stormwater.pca.state.mn.us/index.php/Stormwater_wetlands) without liners should also be avoided where water tables are shallow and the practice would likely intercept the water table. **Bioretention BMPs can be designed and constructed with adjusted** [**media content**](http://stormwater.pca.state.mn.us/index.php/Soil_amendments_to_enhance_phosphorus_sorption) **and** [**media depth**](http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention) according to the [Bioretention Design Guidelines](http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention) to accommodate the pollutants of concern.
* **Consider use of liners, under-drains, or comparable safeguards against infiltration** when runoff exceeds target concentrations.
* **Locate practices offline and minimize offsite run-on** with appropriate diversions.
* **Establish rigorous maintenance and inspection schedules** for practices receiving the runoff from the hotspot areas of concern.

Table 2.8 provides general infiltration guidelines associated with six operational areas. Infiltration at hotspots relies on overall site design and facility operations management. Good design and committed, well-trained facility staff should make infiltration possible for certain areas of the site. Where uncertainty is present, designers should avoid infiltration practices. The Minnesota Department of Health recommends that infiltration of runoff from PSHs, even if they are not actual hotspots, should not be used within the 1 year wellhead protection area and limited in vulnerable wells for the 10 year wellhead protection area.

Table 2.8 Infiltration Guidelines for Potential Stormwater Hotspots

|  |  |
| --- | --- |
| Operational Area | Potential Infiltration Guidelines |
| Landscaping | Infiltration is okay as long as there is no run-on or co-mingling from higher pollutant loading areas and appropriate pre-treatment is provided for the specified practice. Chemical management is needed to limit the amount of fertilizer and pesticides added to the turf. |
| Downspouts | Infiltration is ok as long as there is no run-on or co-mingling from higher pollutant loading areas, there is no polluting exhaust from a vent or stack deposits on the rooftop, and there is appropriate pre-treatment provided for the specific practice. |
| Vehicle Operations | Infiltration is ok with the following provisions:   * No run-on from higher pollutant loading areas * Limited salt application or sue of alternative deicers * Enhanced pre-treatment requirements such as (suggested unless better local information is available) minimum vegetative filter lengths of 20 feet, maximum velocity in conveyance channels to infiltration practice of one foot per second, plunge pools and sediment basins/chambers with volumes of at least 25”% of the water quality volume * Only daily “commuter” parking areas and no long-term car/truck storage sites. |
| Waste Management and Outdoor Material Storage\* | Infiltration is not typically recommended but it is possible where spill prevention and containment measures are in place, such as catch basins inserts and oil and grit separators. Infiltration is also possible if redundant treatment is provided such as filtering prior to infiltration. Infiltration should be prohibited in areas of exposed salt and mixed sand/salt storage and processing. |
| Loading docks\* | Infiltration is not typically recommended but it is possible where spill prevention and containment measures are in place, such as catch basins inserts and oil and grit separators. Infiltration is also possible if redundant treatment is provided such as filtering prior to infiltration. |
| Vehicle fueling\* | Infiltration is not allowed by the MPCA for new construction under the CGP. |
| Highways\* | Infiltration is possible where enhanced pre-treatment is provided as described under parking lots. Where highways are within source water protection areas and other sensitive watersheds, additional measures should be in place such as spill prevention and containment measures (e.g., non-clogging catch basin inserts and oil and grit separators. |
| \*indicates operational area with likelihood of having higher pollutant loadings | |

1. Information in this section was obtained from the Low Impact Development Manual for Michigan (SEMCOG, 2008). [↑](#footnote-ref-1)